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# An Assessment of Thermal Comfort and Users' "Perceptions" in office buildings - Case of arid areas with hot and dry climate -

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**Abstract**

Comfort is a global concept: heat and cold, light, noise, landscape, water, greenery, prestige.... and other, are as several elements defining different climatic, aesthetic and psychological parameters of comfort. Comfort is also the subjective feeling which does not exist in itself. It is only by discomfort that one can appreciate it. This appreciation is different according to the society and for the same society according to the individuals.

Researchers start to defy the theory of universality, and to discuss that the fact of not consider: cultural, social, economic and climatic dimensions in the evaluation of comfort, direct to an exaggeration in the definition of the heating and air-conditioning needs, for the reason of the universal application of the thermal comfort tools of evaluation that a significant thermal discomfort is perceived by the subjects considered [1]. So there is not perfect combination of comfort conditions since those are not relating with the context, this interaction between the feelings and differences in appreciation for an individual to a different, and for a society to another. However, the theoretical definitions of the comfort concept agree all on the importance of thermal comfort. This one constitutes the subject of this study. Indeed, recent work on the concept of adaptive comfort proposes the individual variations of the place and time, conduct by personal strategies, which can be of a physiological, psychological, social, cultural and behavioral nature. In inverse of the physiological answers, which can be measured in an objective way, the determination of the subjective answers depends on the self-evaluation of the person subjected to a given environment. This evaluation is not single but varies with the individuals, and also for the same individual according to various periods [2.3].

*Key Words:* Bioclimatic strategies of evaluation, thermal comfort, perception, thermal indexes, semantic differential scales, thermal comfort Re-humanization, thermal simulation, Climate Consultant 04 (CC04).


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## 1. Introduction

Between objective and subjective, the determination of the thermal comfort notion and the finality of this work are to manage and to improve the evaluation method of thermal comfort by the analysis of the various intervening parameters quantitatively and qualitatively [1]. With an approach under "single condition" with regard to the thermal comfort of the interior environments, significant cultural, social and contextual factors are ignored and can lead to an exaggeration of the needs for air-conditioning [4]. Therefore, the anxiety will be set on the strategies of thermal comfort real evaluation in the office buildings of various types and in a zone concerned by an extreme climate, with an aim of adopting accessible solutions to the architects, with means which are familiar for them. Thermal comfort is difficult to measure because it is highly subjective. It depends on the air temperature, humidity, radiant temperature, air velocity, metabolic rates, and clothing levels and each individual experiences these sensations a bit differently based on his or her physiology and state.

According to the ANSI/ASHRAE Standard 55-2010, thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation[13]."Also known as human comfort, thermal comfort is the occupants' satisfaction with the surrounding thermal conditions and is essential to consider when designing a structure that will be occupied by people. A cold sensation will be pleasing when the body is overheated, but unpleasant when the core is already cold. At the same time, the temperature of the skin is not uniform on all areas of the body. There are variations in different parts of the body which reflect the variations in blood flow and subcutaneous fat. The insulative quality of clothing also has a marked effect on the level and distribution of skin temperature. Thus, sensation from any particular part of the skin will depend on time, location and clothing, as well as the temperature of the surroundings [6].

## 2. Study problem

Comfort and wellbeing are today in the center of the concerns of each consumer, user or prescriber of products or services, and the universe of building does not escape the rule. Inside the development of competition in the field of the energy services, it seems paramount today to better knowing the individuals needs as for the conditions of comfort in the buildings, and more particularly as for the thermal conditions. Nevertheless, this task is very complex: there is not single customer but a multitude, having often opinions, attitudes, and contradictory behaviors [6]. For more than eighty 80 years, the study of thermal comfort has mobilized the scientific community: physiologists, physicists, ergonomists, sociologists and other trying to predict the reactions of the individuals under given climatic conditions. The majority of last and current researches in building making are based on a whole of standardized criteria, which are defined for a "standard individual", and which rest on physical and/or physiological considerations concerning the interaction between Man and its thermal environment. Comfort is often associated there an «absence of discomfort ", "*an absence of feelings*" Or with «neutrality inside thermal environment" [5,11].

## 3. Study objectives

This study showed the significant differences between thermal comfort calculated and achieved from the bioclimatic analysis tools and that perceived by the office buildings occupants, through the arid zones with hot and dry climate.

## 4. Method

In this dissertation, the comparative and analytic approach used, is based on the study three selected cases is applied for two months (March and June) between the calculated thermal comfort (*bioclimatic techniques*) and the perceived thermal comfort (*perception* evaluated by the *semantic differential scale).* The techniques of the bioclimatic analysis are used at the base of the traditional psychrometers and the thermal simulation software (CC04)[†] .

[†] Climate Consultant is a simple to use, graphic-based computer program that helps architects, builders, contractor, homeowners, and students understand their local climate. It uses annual 8760 hour EPW format climate data that is made available at no cost by the Department of Energy for thousands of weather stations around the world. Climate Consultant translates this raw climate data into dozens of meaningful graphic displays. The purpose is not simply to plot climate data, but rather to organize and represent this information in easy-to-understand ways that show the subtle attributes of climate, and its impact on built form. The goal is to help users create more energy efficient, more sustainable buildings, each of which is uniquely suited to its particular spot on this planet [7,8].

## 5. Definition of the case study, Biskra

In this paper, the choice of *Biskra* as a case study permits us to measure the perception of comfort in the office buildings; and to compare it with that achieved from the *bioclimatic analysis tools* in a zone concerned with extreme climates, in order to adopt partial or global architectural solutions to obtain consequently proposals appropriate such areas and such places.

*5.1. Situation and geographic characteristics:*

The territory is divided from the North to the South into climatic zones, as shown in the map of climatic zones of Algeria, Figure 1, Ref. [1]. Biskra, a city of south Algeria, is characterized with the following geographic coordinates:

- City Biskra - Latitude 34.48 ° N - Longitude 5.44 ° E - Altitude 81m

There are high differences in annual and diurnal temperature ranges, and maximum temperatures may exceed 44 ° C in summer; annual rainfall is very low. Winters have sunny and pleasant days with cold nights. Solar radiation is very intense in summer, being able to reach for the warmest month (in this case July), a daily average of 5962 Wh/m2 for a horizontal surface [1].

Annual climatic data for Biskra are summarized with Figures 1 a,b and c

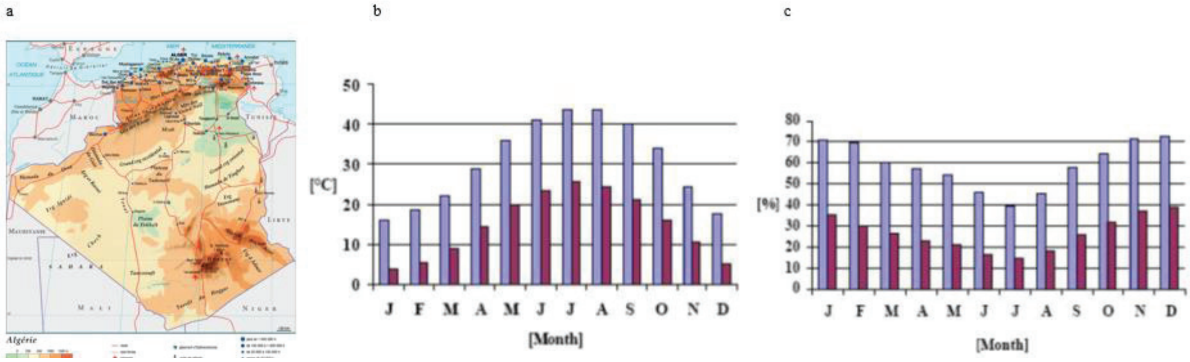


Figure 1: Annual climatic data for Biskra, (a) Climatic map of Algeria; (b) Maximal and minimal monthly temperatures; (c) Maximal and minimal monthly humidities source : author [1]

*5.2. Studied cases*

So that a three typical office buildings were adopted as a test case (*see figure 02*), located in Biskra (Algeria) witch is selected for its representation of the arid areas with hot and dry climate.

- 1st example A.P.C: Colonial building "1800's" with 31 offices and 124 employers
- 2nd example : TAXES's office Post colonial building "1960's" with 18 offices and 72 employers
- 3rd example : D.P.A.T Recent building"1990's" with 24 offices and

In consequence, we have 73 offices and 292 subjects in maximum ( 04 subjects by office)

Figure 02 shoes the three examples in more detail:


Figure 2: studied cases vues and plans, in order 1st example: A.P.C, 2nd example: TAXES's office, 3rd example: D.P.A.T Source: author extract from [1].

*5.2.1. 1st example: A.P.C*

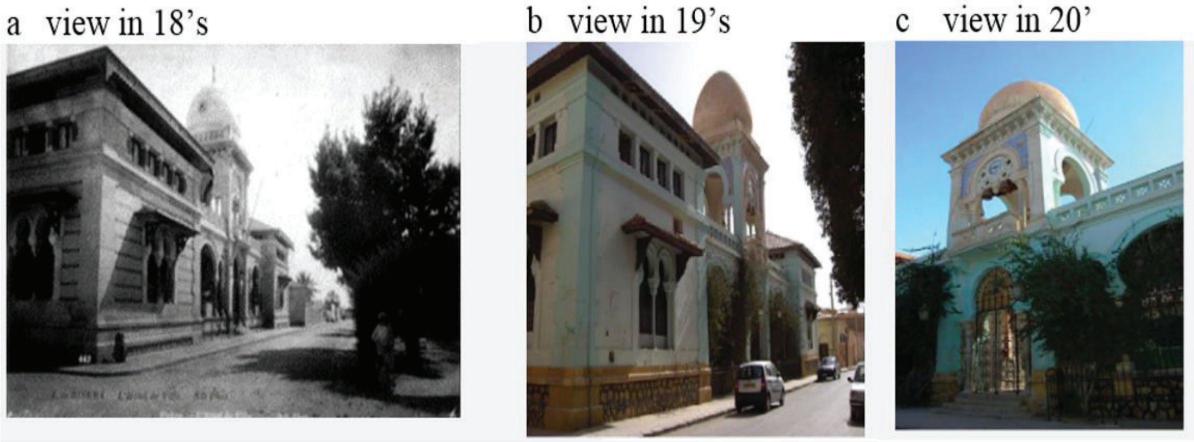


Figure 3: studied cases: 1st example: A.P.C vues and plans, (a) view in 18's (b) b view in 19's, (c) c view in 20'
Source: author extract from [1].

*5.2.2. 2nd example: TAXES's office*

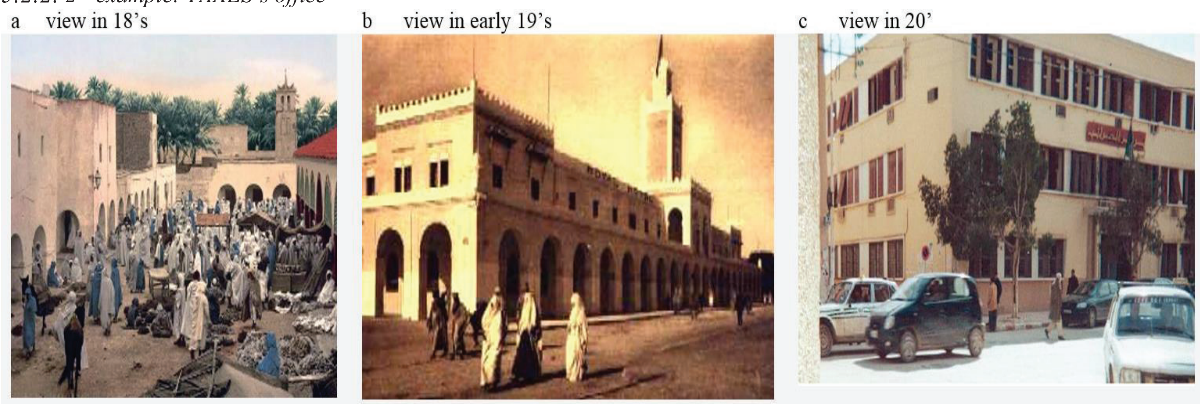


Figure 4: studied cases: 2nd example: TAXES's office vues and plans, (a) view in 18's (b) b view in 19's, (c) c view in 20'
Source: author extract from [1].

*5.2.3. 3rd example : D.P.A.T*

a b c

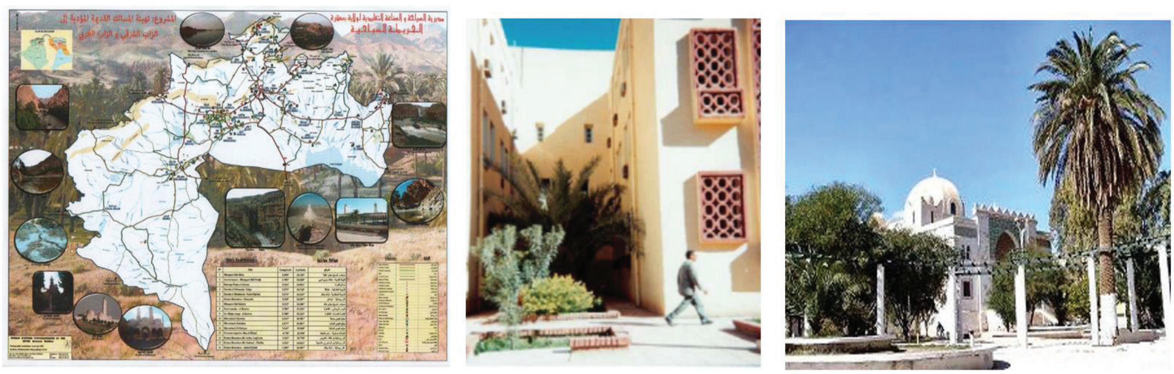

Figure 5: studied cases: 3rd example: D.P.A.T vues and plans, (a) situation (b) b view in 19's, (c) c view in 20'
Source: author extract from [1].

## 6. RESULTS

*6.1- Comparison between perceived thermal comfort and that achieved from Givoni's Psychrometric Chart;*

A psychrometric chart for a given location can tell us information about temperature (wet bulb and dry bulb) and humidity (relative and absolute).‡ While they may seem overwhelming at first, by learning how the variables interact, we can begin to use the psychrometric chart to interpret occupant comfort and effective passive design strategies for our location§. [6]

After the evaluation of thermal comfort in the studied cases, the comparison between the rates of satisfaction of *global* thermal comfort and the predicted comfort achieved from bioclimatic analysis tools will be made at the base of percentages acquired by questionnaire (investigation) for the first variable, and the limits of comfort determined by Givoni's Psychrometric Chart for the second variable. The evaluation of the perception (the rate of satisfaction) provides the real occupant's thermal comfort needs, instead of the needs mentioned from the bioclimatic diagrams.

Therefore, inside the office buildings, satisfaction is evaluated on a semantic scale of five values " -2 -1 0 +1 +2 ", which correspond respectively to «very satisfied, rather satisfied, satisfied, rather not satisfied, and at all not satisfied»:

*For March:*

some 30% of the days of March are integrated in the thermal comfort zone following Givoni's diagram, while the percentages of the occupants satisfaction set out again as follows: 56.60% of people consider their offices comfortable which coincide with value 0 of the Osgood's semantic scale, however only 11.67% of the subjects declare their dissatisfaction by value +1 of the scale which corresponds «rather not satisfied»

Table 1: comparison between perceived thermal comfort and that achieved from Givoni's Psychrometric Chart. March[1].

| perception | very satisfied -2 | rather satisfied -1 | satisfied 0 | rather not satisfied +1 | at all not satisfied +2 |
|---|---|---|---|---|---|
| Percentage % | 0 | 31.67 | 56.60 | 11.67 | 0 |
| Givoni's Psychrometric Chart - Number of days- | 0 | 40% | Comfort Zone 30% | 30% | 0 |

*For June:*

Some 35 % of the days of March are integrated in the thermal comfort zone following Givoni's diagram, while the percentages of satisfaction set out again as follows: 10.84 % of people consider their office buildings comfortable which coincide with value **0** of the Osgood's semantic scale, 45.80 % of the subjects declare their dissatisfaction by value +1 of the scale which corresponds " rather not satisfied " and 43.33% of the subjects judge their dissatisfaction by value +2 of the scale.

Table 2: comparison between perceived thermal comfort and that achieved from Givoni's Psychrometric Chart, June[1].

| perception | very satisfied -2 | rather satisfied -1 | satisfied 0 | rather not satisfied +1 | at all not satisfied +2 |
|---|---|---|---|---|---|
| Percentage % | 0 | 0 | 10.84 | 45.80 | 43.33 |
| Givoni's Psychrometric Chart - Number of days- | 0 | 5 % | comfort Zone 35% | 35 % | 25 |

‡ The psychrometric chart allows for several deductions which affect the design of the built environment. Because it relates, amongst other aspects of temperature and moisture content in the air, it is possible to draw areas of different influences of these variables. Also the psychrometric chart can serve as basis for climate classification and building design strategies according to temperature and humidity [9,10].

§ The results and conclusions of this type of analysis must be considered as an initial guideline only, since it is not the same, for instance, to design a home as an office building with a higher internal load. It is always advisable to develop detailed energy simulations that allow us to identify and quantify optimum strategies for each building and location. But as an initial and broad approximation on first approaching a passive strategy building design, the Climate Consultant is an indispensable tool [7,8].

*6.2. Comparison between perceived thermal comfort and that achieved from the method of Novell:*

After the evaluation of thermal comfort in the studied cases, the comparison between the real comfort perceived by the occupant and the comfort calculated by the bioclimatic analysis will be based on the thermal comfort perception obtained by the questionnaire and the method of Novell §*Figure 6.*

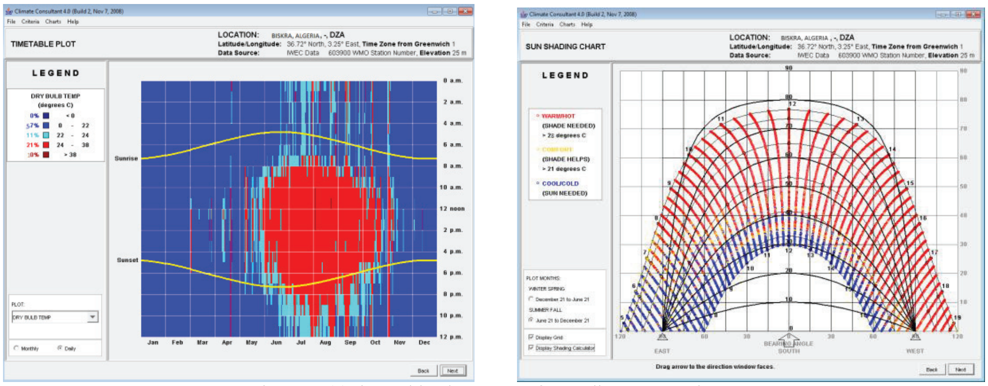


Figure 6: (a) time table plot, extract from Climate Consultant 04 CC04
(b) sun shading chart extract from Climate Consultant 04 CC04

*For March:*

The perception of thermal comfort measured in the investigation is relatively close with the thermal comfort calculated (respectively 37 % and 28 %) with a difference of 9 %.. however the " cold " lasts less longer according to the occupants perception than according to bibliographical calculations' (24.53% against 32%) with a difference of 8 %. While perceived «heat» lasts longer but almost equalizes that evaluated by the bioclimatic tools (respectively 38.47% and 40%) with a difference of 1.53 %.

Table 3: comparison between perceived thermal comfort and that achieved from the method of Novell. March[1].

| perception | Excessively cold | Very cold | cold | Slightly cold | neutral | Slightly hot | hot | Very hot | Excessively hot |
|---|---|---|---|---|---|---|---|---|---|
| value | -4 | -3 | -2 | -1 | 0 | +1 | +2 | +3 | +4 |
| % | 0 | 0 | 8.63 | 15.90 | 37 | 23.80 | 5.9 | 5.9 | 2.87 |
| ∑ | 24.53 | | | | 37 | 38.47 | | | |
| Novell's method | 32 | | | | 28 | 40 | | | |

The results of the questionnaire redefine the real necessities of thermal comfort in the studied cases, which differ appreciably from those of the bioclimatic diagrams. These differences are less significant during March. They present distances which separate calculated comfort and perceived comfort, evaluated has almost the one tenth (8%, 9%).

*For June:*

The perception of thermal comfort measured in the investigation is considerably different with the calculated thermal comfort (respectively 7.5 % and 28 %) with a difference of 20.50 %. However the «cold " lasts as less longer according to the perception of the occupants during June as according to bibliographical calculations' (0% against 32%) with a difference of 32 %. While perceived "heat" lasts also longer and with a great difference than that evaluated by the bioclimatic tools (respectively 92.51% and 40%) with a difference of 52.51 %.

Table 4: comparison between perceived thermal comfort and that achieved from the method of Novell, June[1].

| perception | Excessively cold | Very cold | cold | Slightly cold | neutral | Slightly hot | hot | Very hot | Excessively hot |
|---|---|---|---|---|---|---|---|---|---|
| value | -4 | -3 | -2 | -1 | 0 | +1 | +2 | +3 | +4 |
| % | 0 | 0 | 0 | 0 | 7.5 | 12.5 | 26.67 | 25.84 | 27.5 |
| ∑ | 0 | | | | 7.5 | 92.51 | | | |
| Novell's method | 32 | | | | 28 | 40 | | | |

### *6.3- Comparison between the perceived thermal comfort achieved from the questionnaire and that evaluated by the thermal indices (PMV and Top – the operative temperature):*

Predicted Mean Vote: The Predicted Mean Vote (PMV) refers to a thermal scale that runs from Cold (-3) to Hot (+3), originally developed by Fanger and later adopted as an ISO standard. The original data was collected by subjecting a large number of people (reputedly many thousands of Israeli soldiers) to different conditions within a climate chamber and having them select a position on the scale the best described their comfort sensation. A mathematical model of the relationship between all the environmental and physiological factors considered was then derived from the data. The result relates the size thermal comfort factors to each other through heat balance principles and produces the following sensation scale. Table 5.

Table 5. The recommended acceptable PMV range for thermal comfort from ASHRAE 55 is between -0.5 and +0.5 for an interior space [12,13]

| Value | Sensation |
|---|---|
| -3 | Cold |
| -2 | Cool |
| -1 | Slightly cool |
| 0 | Neutral |
| 1 | Slightly warm |
| 2 | Warm |
| 3 | Hot |
| predicted mean vote sensation scale | |

The comparison will be based on percentages obtained by questionnaire and the thermal indexes (PMV and Top). According to the simulation and the thermal index: The analysis of the thermal comfort shows that for March all the office buildings attain a certain comfort for the reason of their orientations and their built envelopes. While for June the western and southern west directed office buildings (the unfavorable orientations) suffer from a considerable discomfort and an unpleasant thermal environment.

*For March*

Table 6. Comparison between perceived thermal comfort and that achieved from the thermal indices, March [1].

| | | |
|---|---|---|
| Predicted mean vote PMV | -1 < PMV < 1 | 82% |
| Operative temperature (Top) °C | Top for summer: 22.5°C< Top < 28°C | 72% |
| | Top for winter : 20°C< Top < 23.5°C | / |

*For June*

Table 7. Comparison between perceived thermal comfort and that achieved from the thermal indices, June [1].

| | | |
|---|---|---|
| Predicted mean vote PMV | -1 < PMV < 1 | 58% |
| Operative temperature (Top) °C | Top for summer : 22.5°C< Top < 28°C | 43% |
| | Top for winter : 20°C< Top < 23.5°C | / |

The differences are very significant during *summer*. They present long distances which separate calculated comfort and perceived comfort these distances are the difference between the universally technique used of the bioclimatic diagrams and the technique of evaluation by the semantic scales of differentiations [1,14].

## 7. Conclusion

This study showed the significant differences between thermal comfort calculated and achieved from the bioclimatic analysis tools and that perceived by the office buildings occupants, through the arid zones with hot and dry climate. These results are the real representation of thermal comfort perception in the arid areas as *Biskra.* They express on reality, and not on the bibliographical references, the percentages of thermal environments, cold, heat and comfort perceived by the occupants of office buildings. The results of the questionnaire reflect the values of the actual requirements in thermal comfort for the subjects. Thus, predicted comfort and perceived comfort are different and the techniques of evaluation are not adapted to the case of study [1,14].

It results from the comparison between the two thermal comforts (perceived and measured) that:

1. Perception represents the adapted technique for the evaluation of thermal comfort for a given population. What will make it possible to suggest the necessary strategies and sufficient of hygrothermic regulation. This technique will allow also the construction of the limits of thermal comfort, with synchronic measurements in-situ by sophisticated instruments.
2. The thermal comfort perceived by the subjects is different from the thermal comfort evaluated by the bioclimatic tools of analysis. This does not imply that the recommendations deduced by these last are not valid any more, but they are general. They are applicable at the same time for various climates and in various areas. Whereas there are differences in lived of each area and city, according to its social, cultural, economic and climatic particular conditions.
3. A disagreement between calculated thermal comfort and the real comfort perceived by the occupants due to:
   - The temperatures of comfort vary from a study to another.
   - The limits of comfort accepted for a population can be considered different for another (Slightly cool or Slightly warm for example).
   - No consideration of subjective dimensions in the thermal comfort evaluation.
   - Indeed, two people of different cultures and socio-professional areas automatically do not perceive space and its components in the same way and do not attain the same attitudes from it.
   - The recommendations released by the traditional bioclimatic tools are insufficient and enough general for the arid areas characterized by a hot and dry climate…

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